# STUDIES OF ELECTRICAL INTERFERENCE TO RADIO RECEPTION*

By S. C. MAJUMDAR, S. M. SEN

AND

S. R. KHASTGIR

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**ABSTRACT.** Studies in electrical interference from three D.C.-operated electric fans and a motor were made in three frequency ranges : (1) 7 Mc./s-20 Mc./s, (2) 3 Mc./s- 6 Mc./s and (3) .65 Mc./s- 1.5 Mc./s. The studies can be classified as follows :

I. (*a*) Measurements of the r-f radiation field of the electric noise and the corresponding a-f output for different frequencies.

(*b*) Study of the effect of speed variation on these measurements.

It was found from these studies that, in general, the noise field decreased with the increase of frequency *but for some maxima*. The corresponding a-f output was found, in general, to increase with frequency *but for some maxima*. The maxima for the r-f noise field and the a-f output were not always at the same frequencies. The maxima in the noise field appeared to depend on the interfering source. The effect of speed variation was, in general, a decrease in the field with the decrease of speed. The variation of speed did not affect the positions of the maxima.

II. Determination of the resonance frequencies of the armature-sector coils of the different motors.

The experiments were carried out over a wide range of frequencies from .5 Mc./s to 22 Mc./s. The resonance frequencies were obtained and there appeared some correspondence between the resonance frequencies thus obtained and the frequencies corresponding to the observed maxima in the noise field. It was thus conjectured that the *quasi*- continuous type of the r-f noise components would have its maximum intensity in the region of the resonance frequencies as determined by the L-C-R values of the different armature-sector coils.

III. Some measurements of the ratio of the vertical and the horizontal components of the noise field.

IV. An oscillographic study of the r-f noise components :—Evidence was obtained of damped electromagnetic waves over a wide range of frequencies.

## INTRODUCTION

Every radio listener knows that reception of signals is often seriously disturbed by electric fans, electric pumps, refrigerators, electric vacuum cleaners, lifts, electric tramways, trolley buses, motor car and air-craft systems, high frequency transmission systems and various other electrical installations. Some useful and important investigations have already been carried out on this subject of electrical interference. The pioneer work of Howe (1937) on radio interference

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from traction systems, the work of Curtis (1932) on electrical noise from motor cars and aeroplanes, Langton and Bradshaw's (1935) work on high voltage transmission lines, the investigations of Gill and Whitehead (1938) on electrical interference from trolly buses and electro-medical equipments, etc., are worthy of special reference. We should also mention the work of Morris (1934), Neale (1935), Warren (1935-36), Schumacher (1935) and the I.E.E. Council (1934) on the methods of eliminating electric noises and the legislatures concerning them.

In India some amount of work was recently done by S. P. Chakravarty and N. L. Dutt (1941) at the Kanodia Electrical Communication Engineering Laboratories of the Department of Applied Physics in the University of Calcutta. In their work they investigated electrical interference from various sources, such as, D.C.-operated electric fans, pumps and refrigerators on a wide range of wavelengths (10m.- 550m.). Measurements were made of the r-f interfering voltage input to the receiver at some distance from the different noise sources. They also measured the ratio of the horizontally polarized to the vertically polarized components on various wavelengths for the different noise sources. The effect of speed variation of the motors was also studied. An analysis was also made of the power distribution in the audio-frequency bands resulting from the r-f signal from the different sources. In their work Chakravarty and Dutt employed a directional microphone connected to an amplifier system for the measurement of the audio-frequency output. The frequency distribution of the r-f interference voltage input to the receiver as investigated by these workers over a wide range of wavelengths revealed a number of maxima. The cause or causes of these maxima were not, however, explained and this remained a very intriguing and useful subject for investigation.

## SCOPE OF THE PRESENT INVESTIGATION

In the present work a study of radio interference due to the radiation field from two D.C.-operated ceiling fans, a table fan and a D.C. motor, was undertaken. Measurements were made of the normal (vertical) radiation field and the corresponding a-f output voltage across an impedance due to electrical interference from the different noise sources in three specified ranges of broadcast frequencies—low, medium and high. Maxima were observed at specified frequencies. The effect of varying the speed of the motors on these measurements was studied. A reduction in speed appeared, in general, to reduce the interference effect, while the positions of the noise maxima in relation to frequency remained the same inspite of a considerable variation in speed. The ratio of the vertically polarized to the horizontally polarized fields was also determined for the three ranges.

The works of Howe on radio interference from traction systems strongly suggested that the maxima in the r-f interference field should be associated with the resonance frequency of the armature-sector circuit in the electric-motors. In a D.C.-operated motor, it is clear that the electrical interference is due to sparking between the brushes and the approaching or receding commutator. The 'reactance voltage' in the armature coil which is developed as a result of change of current in it, frequently causes sparks and the duration of the sparking is usually somewhat prolonged due to self-inductance of the coil. With the higher speed of the motor, the reactance voltage in the armature increases, resulting in sparking of greater intensity between the brushes and the commutator segments which approach towards or recede from one or the other of the two brushes. For a particular spark, it is evident, the frequency of the damped oscillations set up would depend not only on the inductance of the armature coil in one sector and its resistance and self-capacity but also on the resistance of the air-gap across which the spark takes place. This resistance may vary between wide limits, especially under irregular spark conditions. Thus it is expected that there would be a large number of frequency components, each being associated with a distinct spark having a definite air-gap resistance. It can also be conjectured that the frequency component having the maximum intensity should lie in the region of the resonance frequency of the armature-sector circuit. Work was therefore undertaken to determine the resonance frequency or frequencies of the armature-sector coil over a wide range of frequencies, well covering the ranges for which the noise measurements were made. The resonance frequencies of the armature-sector coils for the different motors in the specified frequency ranges showed some correlation with the positions of the maxima observed in the noise field measurements.

That the interfering elements, from sources like the fan motors, really consist of damped waves of a very wide range of frequencies was shown from the oscillographic studies of the high frequency components as picked by a suitable L-C circuit and applied after suitable amplification to the oscillograph. The low frequency oscillograms of the periodically varying current in the armatures of the different motors were also examined.

The make, type and other details of the fans and the motor employed in the investigation are given in Table I.

TABLE I

| Interfering Source | Make | Type | Remarks |
|---|---|---|---|
| A. D.C. Ceiling fans | 1. Osler | | Volts : 220 V<br>Amperes : .41 A |
| | 2. G.E.C. (Malaya) | | Volts : 220 V<br>Amperes :-- |
| B. D.C. Table fan | Sprague Electric Co., New York. | Lundell Motor Model 30030 | Volts : 225 V<br>Amperes : .4 A |
| C. D.C. Motor | Adair, Dutt & Co. | G.M. 5/6 | Volts : 220 V<br>Amperes, 65 A |

## THE NATURE OF THE ELECTRICAL NOISE FROM D.C.-MOTORS

As has already been explained a large number of damped waves having a wide range of frequencies is expected to radiate from the noise source in a D.C.-

motor. There is also experimental evidence to show that the motor can be regarded as a source of r-f energy giving a *quasi*—continuous spectrum. The receiving set picks up a very small part of this interference spectrum and gives an a-f output in the loudspeaker. The integrated field of the interference signal within the discrete band width containing noise components can then be written

$$E_t = a_0 \cos(\omega t + \theta_0) + a_1 \cos[(\omega + p_1)t + \theta_1] + a_2 \cos[(\omega + p_2)t + \theta_2] + \ldots + \Sigma a_n \cos[(\omega + p_n)t + \theta_n] \ldots \quad (1)$$

where $p_1/2\pi$, $p_2/2\pi$, $p_3/2\pi$ ... are frequency differences between the interfering voltage frequencies and the frequency $\omega/2\pi$ to which the receiver is tuned, $\theta_0, \theta_1, \theta_2$ ... are the epoch angles of the components of the interference spectrum relative to the component having the same frequency as that to which the receiver is tuned and $a_0$, $a_1$, $a_2$, ... are the amplitude of the several components.

It is however permissible to assume that the amplitudes of the individual components $a_0$, $a_1$, $a_2$, $a_3$, etc., of the electrical noise within the usual acceptance band (20-30 kc/s) of a good receiver are of practically the same value. The expression (1) may therefore be reduced to

$$E_t = a \sum \cos[(\omega + p_n)t + \theta_n] \quad (2)$$

The variation of the noise field in different frequency channels would evidently depend on the energy distribution in the r-f components emanating from the noise sources in the electric motor.

In our measurements the frame aerial was tuned so that the voltage V developed due to the interference signal across the tuning condenser would be proportional to $\{E.f^2/R\}$, where E is the noise field, $f$ the frequency and R the H. F. resistance of the aerial. If we take $R \propto \sqrt{f}$, then $V \propto E.f^{\frac{3}{2}}$. It is thus evident that the nature of variation of the input voltage V with frequency $f$ would necessarily be different from that of the variation of the noise field with frequency. In a superheterodyne set the a-f current output $i$ can be taken proportional to the input voltage, so that $i = K.E.f^{\frac{3}{2}}$, where K is a constant.

Usually the noise field E is found to decrease with the increase of frequency $f$, so that $\frac{\partial E}{\partial f}$ is negative. Taking the a-f current output to be proportional to $(f^{\frac{3}{2}}.E)$, the variation of this output with frequency would be given by

$$\frac{\partial i}{\partial f} = \tfrac{3}{2} k f^{\frac{1}{2}} \left[ E - \tfrac{2}{3} f \frac{\partial E}{\partial f} \right] \quad \ldots \quad (3)$$

Thus $\frac{\partial i}{\partial f}$ is negative or positive, according as $E <$ or $> \frac{2}{3} f \frac{\partial E}{\partial f}$. In other words, when the noise field is found to decrease with frequency, the acoustic output would increase or decrease with frequency according as the noise field E is greater or less than $\frac{2}{3}f\frac{C_E}{C_f}$. Usually the former alternative holds; the $a-f$ output in that case increases with frequency.

## EXPERIMENTAL METHOD AND DETAILS

In the present work, the $a-f$ noise output current was measured by calibrated radio receiver provided with an output valve-voltmeter, the input terminals of which were connected across the secondary of the loudspeaker transformer. The valve-voltmeter consisted of a suitable valve with a mirror galvanometer in the anode circuit. The anode current was balanced for no signal. After having tuned the frame aerial and also the receiver to a particular frequency, the fan motor was switched on and the change in the deflection of the valve-voltmeter noted. The average of a number of such observations was then determined for a particular frequency. Observations were taken in this way for several frequency channels. From the calibration graphs of the receiver obtained for the different frequencies, the noise input voltage into the receiver was obtained for these frequencies. The field-strength was then calculated from the standard formula.

In some of the measurements, R. L. Moore's (1930) integrating device was employed. The principal feature of this device was that the voltmeter responded to pulses of short duration and at the same time averaged the effect over a much longer time. The grid time-constant was about .4 m sec. and the discharge time-constant of the anode circuit, having a galvanometer in it was roughly .4 sec. This integrating device was found very sensitive.

A superhet set (Philips 313H) was employed in this work after removing the A. V. C. connections. The interfering sources were placed at a distance of about 50 ft. from the centre of the frame aerial. The vertical plane of the aerial was directed towards the noise source. To avoid the antenna effect, the aerial was earthed at the middle point of the length of wire.

All the experiments were performed in a large room with a few electric wirings in it and these wirings too were well shielded. The effect of the wirings conducting the waves from the noise source to the vicinity of the aerial to be picked up again by the receiver by radiation or induction was therefore extremely small.

## EXPERIMENTAL RESULTS

*Measurements of the vertical radiation field and the corresponding a-f output due to electric noise from the different motors*

The measurements were made on three specified frequency ranges: (1) 7 Mc./s-20 Mc./s (2) 3 Mc./s-6 Mc./s(3) .65 Mc./s -1.5 Mc./s. The induction field can be altogether neglected for the first two frequency ranges and for the lowest frequency range also it was small. The measurements were usually made for three regulator positions of each motor. For these positions the voltages applied to the motor were 213 V, 177 V and 151 V approximately. The corresponding speeds varied between 500 and 3000 r.p.m. approximately for the different motors.

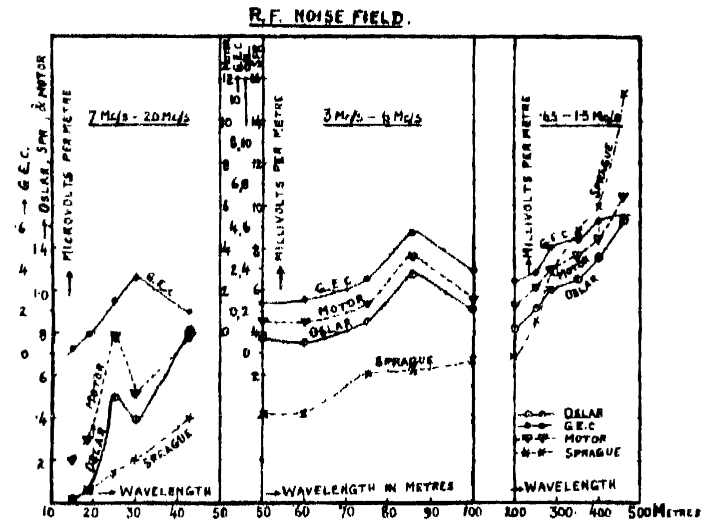


FIG. 1

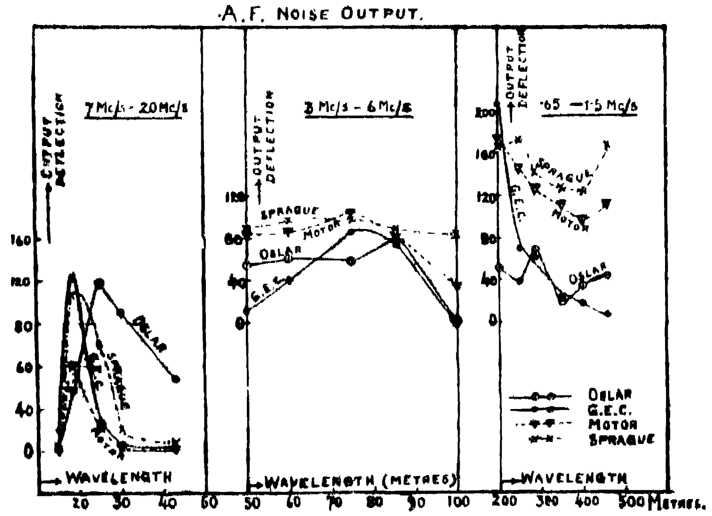


FIG. 2

Fig. 1 gives a set of typical curves showing the r-f noise field for different wavelengths from 15m to 462 meters (.65 Mc./s-20 Mc./s) for the maximum speed of the D. C. motor and the three fans. A similar curve is drawn for the a-f output in Fig. 2. The relative values of the r-f noise field and the a-f output for the different interfering sources are quite *arbitrary*. These curves clearly indicate that the noise field increased in general with wavelength, whereas the a-f current output decreased in general with the increase of wavelength, *but for some maxima at certain definite wavelengths*. The decrease of the a-f output with the increase of wavelength has been explained in the previous section.

The positions of the noise field and the acoustic output for the different interfering sources are given in Table II.

TABLE II

Frequency $f$ in Mega-cycles/sec. and Wavelength $\lambda$ in metres.

| Interfering Sources | | Noise Field Maxima .05–1.5 Mc./s | Noise Field Maxima 3–6 Mc./s | Noise Field Maxima 7–20 Mc./s | Acoustic Output Maxima .05–1.5 Mc./s | Acoustic Output Maxima 3–6 Mc./s | Acoustic Output Maxima 7–20 Mc./s |
|---|---|---|---|---|---|---|---|
| 1 D. C. Motor | f | — | 3.5 | 12.0 | - | 4.0 | 16.0 |
| | λ | - | 85.7 | 25.0 | — | 75.0 | 18.75 |
| 2 Osler Ceiling fan | f | | 3.5 | 12.0 | 1.05 | 3.5 | 12.0 |
| | λ | — | 85.7 | 25.0 | 285.7 | 85.7 | 25.0 |
| 3 G. E. C Ceiling fan | f | | 3.5 | 10-12.0 | - | 4.0 | 16.0 |
| | λ | - | 85.7 | 25-30.0 | - | 75.0 | 18.75 |
| 4 Sprague Electric Co fan | f | - | 4.0 | — | 1.2 | 4.0 | 16.0 |
| | λ | | 75.0 | — | 250.0 | 75.0 | 18.75 |

The noticeable features in the results shown in Table II are :

(*i*) The maxima in the noise field did not appear in the same wavelength or frequency regions for all the interfering sources.

(*ii*) The maxima in the noise field and those in the acoustic output were not always at the same wavelength or frequency regions for a particular interfering source.

## THE EFFECT OF VARYING THE SPEED OF THE MOTORS OF ELECTRICAL INTERFERENCE

The experimental results showed that the r-f noise field usually increased with the increase of the speed of the motors. In certain frequency channels and for some noise sources irregularities in this respect were observed—even though the experiments showing these anomalies were performed with the same degree of care and attention. Special mention should be made of the D. C. motor. The oscillograms of the current fluctuations in the armature of this motor showed secondary fluctuations due to sparks across each pair of the commutator segments, besides the main fluctuation corresponding to the periodicity of the motor. With such a complex source of electrical interference, erratic observations in respect of the effect of speed variation are to be expected.

Fig. 3 illustrates three sets of results—one set with the Osler ceiling fan on 10 Mc./s (30m.) and the other two sets with the D. C. motor on 4 Mc./s and 5 Mc./s (75m. and 60m.) respectively. The observations with the Osler fan on 10 Mc./s showed a gradual increase of the r-f noise field with the increase of speed, whereas with the D. C motor on 4 Mc./s and 5 Mc./s, the noise field at first increased and then decreased with the increase of the speed.

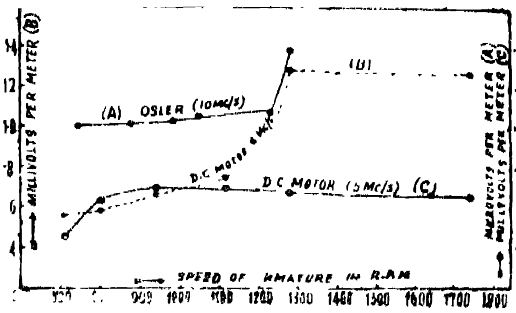


FIG. 3

## RESONANCE STUDIES OF THE ARMATURE-SECTOR OF THE DIFFERENT MOTORS

The circuit diagram of the experimental arrangement is shown in Fig. 4. A particular armature-sector was placed in series with a metal-film resistance (10 ohms and sometimes 100 ohms) having no inductance and capacity. The two ends of the circuit were connected to the output terminals of a signal generator through the knife-switches at either end. Keeping the input voltage constant the alternating P.D. across the metal-film resistance was then tested by a valve-voltmeter for various frequencies from 1Mc./s to 23 Mc./s and in one case from .5 Mc./s to 22 Mc./s. The valve-voltmeter had a mirror galvanometer in the anode circuit and the anode current was balanced with knife-switches on, but with the power key of the signal generator off. With the galvanometer key off in the anode circuit of the valve-voltmeter, the power key of the signal generator was then switched on and the output voltage adjusted at a definite value for a particular frequency. The galvanometer key was then closed and the position of the deflected light spot noted. The power key of the signal generator was then switched off and the change in position of the light spot recorded. Similar procedure was adopted for different frequencies and care was taken that for each frequency the output reading of the signal generator was exactly the same. The change in the galvanometer deflection could be regarded as a measure of the P.D. across the metal-film resistance. When the impressed frequency would be equal to the natural frequency of the circuit containing the armature-sector of some inductance and self-capacity, the current through the circuit would be maximum and so also the P.D. across the pure resistance. The peak in the curve showing changes of galvanometer deflection for different frequencies in the present experiment would evidently enable us to locate the resonance frequency of the circuit. Outside the region of resonance, the P.D. across the resistance would increase with frequency, since the resistance would increase steadily with the increase of frequency of the H.F. current. The results are illustrated in Fig. 5 which shows the resonance peaks.

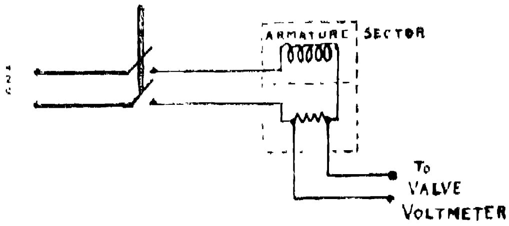


FIG. 4

The positions of the resonance peaks are given in Table III.

Considering the entire frequency range from 75 Mc./s to 20 Mc./s, a very prominent peak in the value of the ratio of vertical to horizontal noise fields was observed at 12 Mc./s (25m.). These were minor peaks. One in the region 1 Mc./s and another in the region 3-4 Mc./s. It is significant that vertical noise-field maxima appeared in these frequency regions.

TABLE III

| — | Frequency range | Observed Resonance frequencies | Frequency range | Positions of Noise-field Maxima |
|---|---|---|---|---|
| (1) D.C. motor | .5 Mc./s to 23 Mc./s | 3.5 Mc./s and 19 Mc./s | .65 Mc./s to 20 Mc./s | 3.5 Mc./s and 12 Mc./s |
| (2) Osler fan motor | 1.0 Mc./s to 23 Mc./s | 3.5 Mc./s, 14 Mc./s* and 20 Mc./s* | ,, | 3.5 Mc./s and 12 Mc./s |
| (3) G. E. C. fan motor | ,, | 4.5 Mc./s (flat resonance) | ,, | 3.5 Mc./s and 12 or 10 Mc./s |
| (4) Sprague Electric Co. fan motor | ,, | 4.0 Mc./s only | ,, | 4.0 Mc./s only |
| (5) India fan motor | ,, | 3.6 Mc./s only. (flat resonance) | No observations | — |

The observed positions of the noise field maxima are also entered in the same table for comparison. The comparison, no doubt, shows some correspondence between the noise field maxima and the observed resonance frequencies. It is curious that the D.C. motor, the G.E.C. fan motor and sometimes the Osler fan motor gave noise field-strengths in the same frequency regions, *viz*., 3.5 Mc./s and 12 Mc./s. The Sprague Electrical Co. fan did not, however, show any maximum in the high frequency region and there was also no resonance observed in the armature-sector circuit in the same range. It is indeed probable that the three motors showed the maximum noise field in the same frequency region, because of the similar L-C-R values of their armature-sectors. It is therefore much more than mere speculation to say that the noise field peaks are associated with the resonance frequencies of the armature-sector. In the case of the G.E.C. fan, there was an indication of a flat resonance peak in the region 4.5 Mc./s only. There was no evidence of any resonance in the high frequency range. The resistance of the armature coil of the G.E.C. fan was fairly high (which would account for its very low speed) and it is very likely that the high damping in the circuit was perhaps responsible for masking the resonance effect. With the motors used in the investigation, the lowest frequency where a maximum in the noise field was observed was 3.5 Mc./s. A scrutiny of the noise field curves (Fig. 1) will show 'bulges' at 1.05 Mc./s for the Osler and the G.E.C. ceiling fans and for the D.C. motor.

That the observed resonance maxima shown in Fig. 5 were real resonance effects were tested in a number of ways :

* For a different sector of the armature, the corresponding resonances were at 13 Mc./s and 18 Mc./s.

(1) When the armature-sector was replaced by a metallic resistance the maximum was smoothed out.

(2) When an additional inductance or capacity was added in series with the armature-sector and the metal-film resistance, the maximum shifted in the right direction.

(3) The evidence of resonance was also obtained with a different circuit arrangement.

A typical result showing the shift of the maximum towards the region of lower frequencies by inserting additional inductance or capacity in series with the actual circuit is illustrated in Fig. 6.

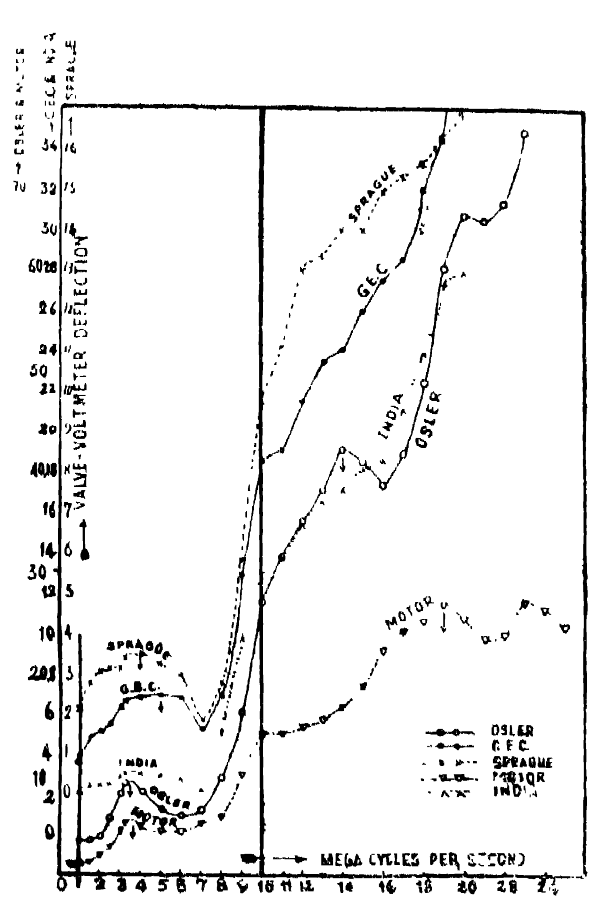


FIG. 5

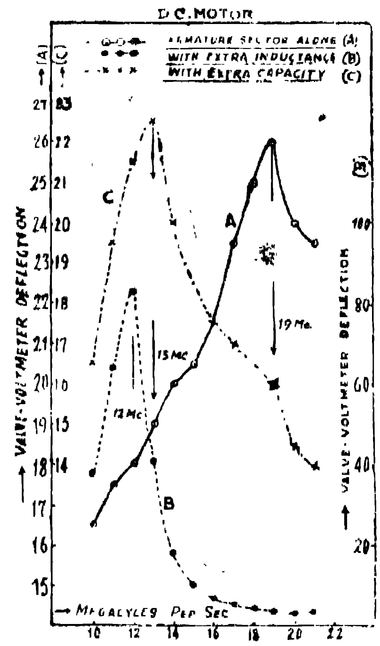


FIG. 6

MEASUREMENT OF THE RATIO OF THE VERTICAL AND THE HORIZONTAL COMPONENTS OF THE NOISE FIELD

The measured values of the ratio of the vertical and the horizontal components of the noise field in the case of the Osler ceiling fan for the three frequencey ranges are shown in Fig. 7. Regarding this variation of the ratio V/H with frequency, the following observaions can be made:

Over the entire frequency range from .75 Mc./s to 20 Mc./s, there was observed a very prominent peak in the value of the ratio of vertical to horizontal noise fields at 12 Mc./s (25 m.). There were two other smaller peaks, one in the neighbourhood of 1.0 Mc./s and the other in the region, 3-4 Mc./s. It is significant that the noise field maxima appeared in the same regions.

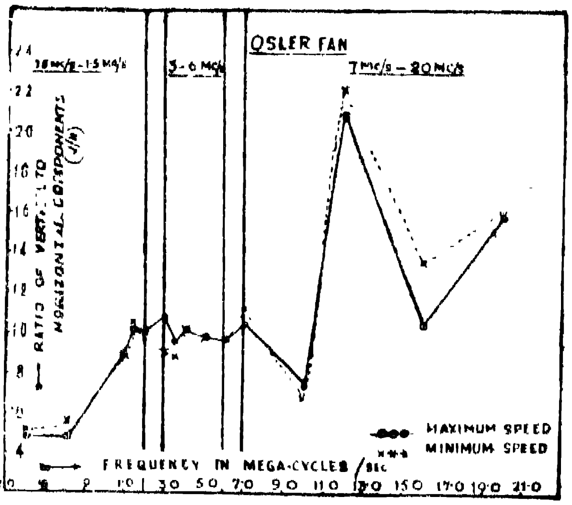


FIG. 7

In the region of the lowest frequency under investigation, the horizontal noise field was about twice as great as the vertical field. As the frequency increased, the vertical field increased as compared with the horizontal field and the two fields became nearly equal at 1.2 Mc./s The two fields remained fairly equal over the entire range, 3 Mc./s—6 Mc./s. (In the latter part of this range and in the first part of the high frequency range 7 Mc./s—20 Mc./s, the horizontal field was however slightly in excess). For still higher frequencies, the vertical field predominated and at its highest the vertical field was found more than double the horizontal field. The ratio V/H decreased, *in general*, as the speed of the motor was reduced.

Too much emphasis cannot be laid on this study. As the experiments were not carried out in an open space, it was possible for the aerial to have picked up reflected radiation from the walls of the room.

### OSCILLOGRAMS OF THE HIGH FREQUENCY COMPONENTS OF THE DAMPED ELECTRICAL OSCILLATIONS DUE TO SPARK DISCHARGES IN THE MOTORS

A calibrated wave-meter circuit containing a variable condenser and a suitable inductance coil was arranged with the coil placed near the armature segments of the motor under investigation. The circuit picked up a particular frequency corresponding to the natural frequency of the circuit, from the various components of different frequencies present at the source, and this was amplified by the H. F. amplifier. The oscillogram did not however represent the exact wave-form of the particular component from the noise source. The damping of the wave-meter circuit introduced a certain modification in the original wave-form.

The oscillograms showed that in the range of wavelengths from 150 m. to 2000 m., the amplitude of the damped waves diminished with the increase of wavelength as effected by varying the calibrated condenser of the wave meter circuit. A typical oscillogram in the case of the D.C. motor is shown in Fig. 8. The natural frequency of the wave-meter circuit in this case was 155 m.

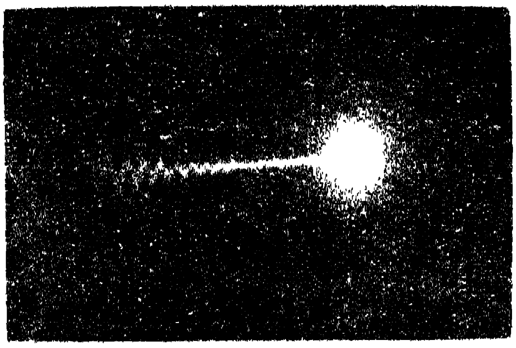


FIG. 8

In conclusion we record our thanks to Mr. S. P. Chakravarty for useful suggestions and to Prof. S. N. Bose for his interest during the progress of the work.

PHYSICS DEPARTMENT,
DACCA UNIVERSITY.

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